

SEASONAL VARIATIONS IN RELATIVE ABUNDANCE OF
CYCLOPS VERNALIS FISCHER, *CYCLOPS BICUSPIDATUS*
CLAUS, AND *MESOCYCLOPS LEUCKARTI* (CLAUS)
IN WESTERN LAKE ERIE, FROM JULY, 1946,
TO MAY, 1948

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Examination of the limnological literature shows that very few year-round quantitative studies have been made on zooplankton. Most of the literature contains reports of data that have been gathered during the summer months. Extensive year-round research results on zooplankton and related limnological factors have been published by Kofoed (1908), Allen (1920), Birge and Juday (1922), Riley, (1940), and Pennak (1949). Several year-round limnological studies of western Lake Erie have been made (Chandler, 1940, 1942, 1944; Chandler and Weeks, 1945).

The purpose of this study was to make quantitative determinations of seasonal variations in temperature, in abundance of seston, and in abundance of two species of *Cyclops* and one species of *Mesocyclops* by making at least monthly collections at one meter intervals from surface to bottom for 21 months.

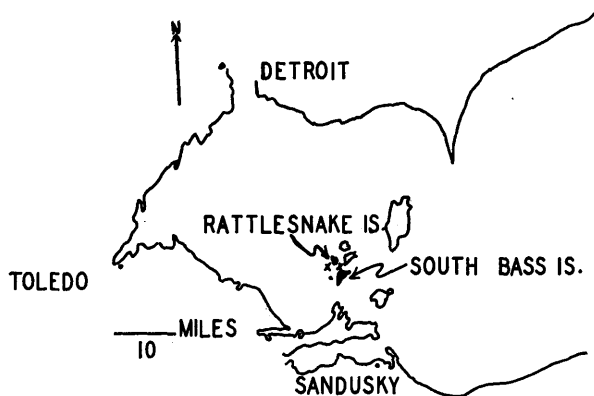


FIGURE 1. Outline map of western Lake Erie. The two crosses between South Bass and Rattlesnake Islands indicate where collections were made.

Appreciation is expressed to Dr. David C. Chandler and to Dr. W. J. Jahoda for their assistance both in the field and laboratory; to Miss Lois Redmond for preparation of graphs; to my associates at Kansas State Teachers College, who have helped on many occasions; and to The Franz Theodore Stone Institute of Hydrobiology for furnishing all of the field and laboratory equipment, which was used to gather data for this study.

DESCRIPTION OF AREA

Figure 1 shows the locations of the two stations where all collections were made. Station I was located about half-way between South Bass Island and Rattlesnake Island where the water was 10 meters deep. All collections were made at this location when an ice cover existed. Station II was located about 2 miles northwest of Station I where the water was also about 10 meters deep.

Collections were made at station II whenever an ice cover did not exist. Since there was considerable evidence that the limnological characteristics of the water in the area of these two stations is about the same (Chandler, 1940; Andrews, 1948), the data are treated as though they were collected at one station representative of this area of western Lake Erie.

MATERIALS AND METHODS

Quantitative zooplankton samples were taken at each meter from surface to bottom with a 10 liter plankton trap (Juday, 1916). All adult male and female *Cyclops* and *Mesocyclops* in each 10-liter sample were identified to species, counted, and recorded. Immature and naupliar stages were also recorded.

Water samples for purposes of making seston determinations were collected with a two-liter capacity modified Kemmerer water bottle. A two-liter sample was taken at the surface (zero meters), halfway (5 meters), and near the bottom (10 meters). These samples were thoroughly mixed and a one-liter sample centrifuged. Organic and inorganic determinations were made according to standard procedures discussed by Chandler (1942).

Temperatures were recorded at zero, 5, and 10 meters with a Negretti and Zambra reversing thermometer.

DISCUSSION OF RESULTS

Cyclops vernalis Fischer. *C. vernalis* (Coker, 1943, Marsh, 1918), which is probably the most widely distributed copepod in North America, was the copepod that occurred in greatest abundance in western Lake Erie during this study. The seasonal trends in abundance of males and females are given in figure 2. In order to have the numerical values in the curve as significant and representative as possible, all males and females in each 10-liter sample at the ten different depths were counted and recorded separately. Therefore each point on the male and female abundance curve represents the total number of males or females per 100 liters.

On July 29, 1946, when the first collections of this study were made, the water temperature was about 24° C and *C. vernalis* was abundant. There were 42 males and 361 females in the 100 liters sampled (fig. 2). The number collected decreased during July and August until on September 3 only 7 males and 61 females were collected. The population then increased until November 21 when 83 males and 442 females were collected. This was followed by a decline in population until on January 24, 1947, only 2 males and 6 females were collected. The water temperature on this date was 0.3° C. Although collections were made twice each month from January to May, only a few scattered specimens were collected. Figure 2 shows that an ice cover existed from December 6, 1946, to March 18, 1947. This species was not collected while an ice cover existed.

In the spring of 1947 (May 9), when the water temperature was 8.4° C., 12 females were collected. On May 19, none of this species was found in the collections, but on June 4, 141 males and 657 females were collected. These results would indicate that this species reproduces rapidly, building up a very high population within a week or two. Development from egg to adult requires only about eight days, according to Ewers (1930). One can readily see that collections made less often than once a month, every month of the year, would not obtain results that would indicate such tremendous fluctuations in population as shown by these data. As shown in figure 2 the peak population occurred on June 14 and July 5, 1947, when the water temperature was 17.6° and 21.7° C, respectively. During early August, the number collected decreased to a low of 6 males and 52 females. There was a slight fall peak in the population, as indicated by the September-October collections. Collections were not made in November, but this species was not in collections taken from December 2 to April 24, although collections

were made every month. The ice cover (fig. 2) in 1948 was of shorter duration than the ice cover of the previous year. It appeared on January 27 and disappeared on March 15. It is interesting to note that, again, *C. vernalis* was not collected under the ice cover. On April 24, 1948, when the temperature was 8.6° C, 4 males and 4 females were collected. This was apparently the beginning of the spring population.

This species occurred in greatest abundance when water temperatures were about 20° C. Decided decreases in abundance occurred when temperatures were as high as 24° C. This species began to appear in the spring when the water temperature increased to 8° or 10° C. The population began to drop off rapidly in the late fall when the water temperature decreased to about 10° C. When the water temperature was as low as 2° or 3° C, *C. vernalis* was not present in the collections. Chandler, 1940, found this species to occur from May to November,

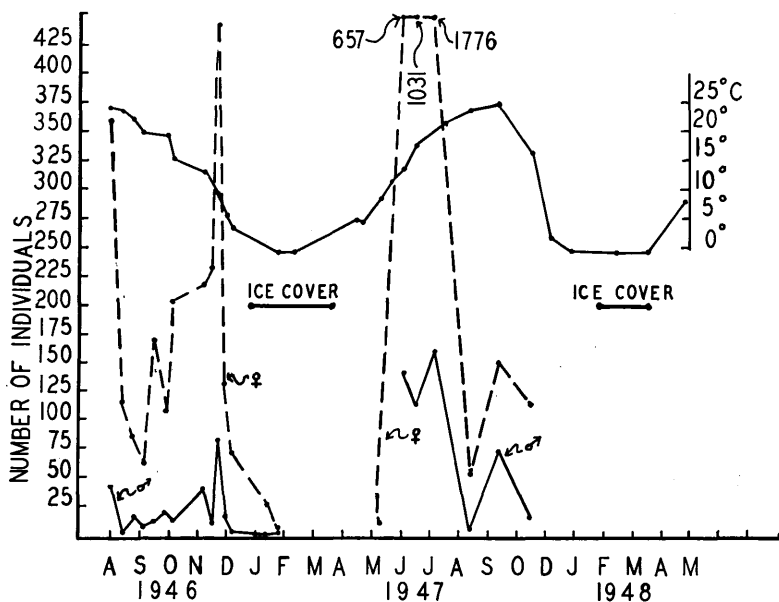


FIGURE 2. Seasonal variations in number of adult male and female *Cyclops vernalis*/100 liters. Each point on the curve represents the total number of individuals found in ten 10-liter samples taken at one meter intervals from surface to bottom. Duration of ice cover and variations in water temperature are also indicated.

but not to exceed 3 per liter. Optimum culturing temperature for this species is about 25° C according to Ewers (1936). The writer's experience in culturing this same species in Lake Erie water, with nutrients added, showed that the greatest rate of reproduction occurred when the culture was maintained at approximately 21° C. It appears that the optimum temperature for *C. vernalis* is about 20° C. in the natural environment in western Lake Erie as well as in the laboratory culture.

Cyclops bicuspidatus Claus. *C. bicuspidatus* was described by Marsh (1918) as a limnetic species, characteristic of the Great Lakes. Ewers (1930) stated that it was a deep water species of Lake Erie. Chandler (1940) found *C. bicuspidatus* throughout the year with the peak of abundance occurring in May or June. This species never was present in numbers exceeding 7 per liter. This study has shown *C. bicuspidatus* to be a cold water form which occurred as the most abundant

cyclops in western Lake Erie for only a brief period in the spring, when a maximum of 11 per liter was found. It never occurred in as great abundance as did *C. vernalis*, which reached a maximum of 19 per liter.

When this study was begun July 29, 1946, *C. bicuspidatus* was not present in the collections. Although collections were made at least once each month from July until January, only an occasional specimen of this species was collected (fig. 3). On January 11, 1947, thirteen females were collected. The water temperature at this time was about 2° C. Males did not appear in the collections until March 3, when 6 males and 20 females were collected in the 100 liter sample. At this time the water temperature was about 0.3° C. Males and females were found in all collections throughout the winter and spring. On June 4 and 14,

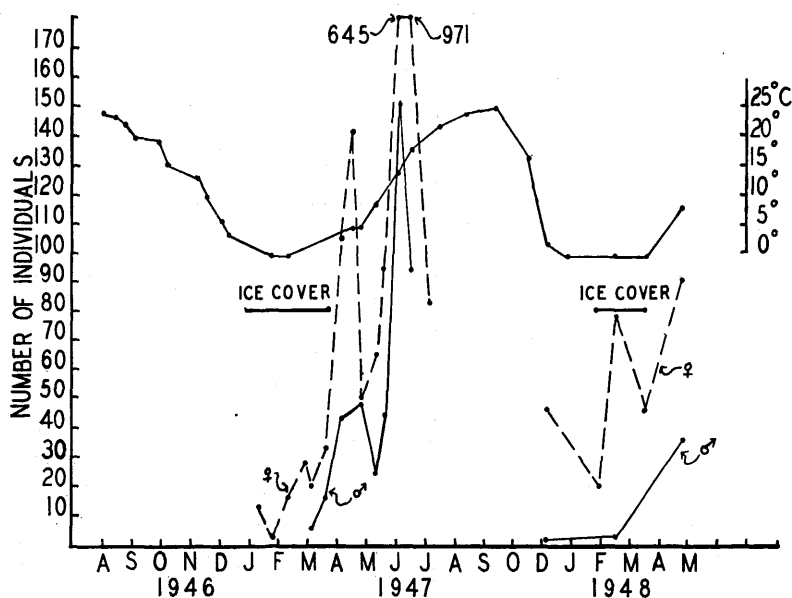


FIGURE 3. Seasonal variations in number of adult male and female *Cyclops bicuspidatus*/100 liters. Duration of ice cover and variations in temperature are also indicated. (For details, see legend of fig. 2.)

when the water temperature was about 15° C, the peak of the *C. bicuspidatus* population occurred. Examination of figure 3 shows that 94 males and 971 females comprised the June 14 collection. On July 5, when the water temperature was 21.7° C and the *C. vernalis* population was at one of its peaks, the *C. bicuspidatus* population consisted of only 83 females and no males.

Throughout the summer and fall of 1947, *C. bicuspidatus* was not found, although collections were made at least every month, excepting November. On December 2, 1947, when the water temperature was about 2° C, 2 male and 46 female *C. bicuspidatus* were collected. Both males and females were collected each month until April 24 when the last collection was made. It may be seen in figure 3 that the population was building up when this study was terminated. If collections had been continued throughout May and June, an annual population peak would probably have been detected as it was in 1947.

An ice cover existed from December 6, 1946, to March 18, 1947, and from January 27 to March 15, 1948. Examination of figure 3 shows that *C. bicuspidatus* was first collected each year either just before or right after the ice cover formed.

The temperature of the water was about 2° C in January, 1947, when they first appeared, and about 1.7° C in December, 1947, when they first appeared. The population apparently reached its peak in the first part of June, 1947, when the water was about 14° C. During both years, the *C. bicuspidatus* population decreased rapidly and disappeared as soon as the water temperature reached about 15° C.

Only scanty information concerning the annual variations in populations of this species can be found in the literature. Ewers (1930) stated that *C. bicuspidatus* may be found in shallow waters in spring and autumn and that it goes to deeper waters of western Lake Erie in June. The results of this study indicated that from July to December this species was not present at any depth in western Lake Erie. Moore (1939) collected *C. bicuspidatus* during the summer and fall at Douglas Lake in Michigan. Langford (1938) collected it, but the numbers of

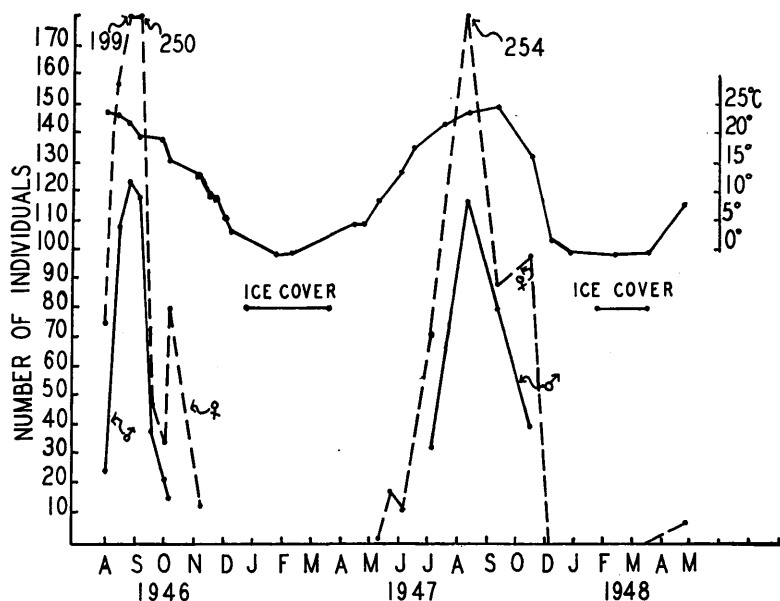


FIGURE 4. Seasonal variations in the number of adult male and female *Mesocyclops*/100 liters. Duration of ice cover and variations in temperature are also indicated. (For details, see legend, fig. 2.)

C. bicuspidatus he collected were lumped with other species; thus it was difficult to tell when the peak of the populations occurred. Chandler (1940) collected it the year-round with very few specimens being taken during the summer. Pennak (1949) collected *C. bicuspidatus* every month of the year in seven different mountain lakes in Colorado, but it was not a species that was characteristic of any particular time of the year. During this study in western Lake Erie, *C. bicuspidatus* was conspicuously monocyclic, appearing only throughout late winter and early spring.

Mesocyclops leuckarti (Claus). Marsh (1918), Ewers (1930), and Chandler (1940) list this species as *Cyclops leuckarti* Claus. Coker (1943) treats the synonyms that have been variously used for this species and gives supporting evidence for the correct name being *M. leuckarti* (Claus). Reports of population studies in North America on *M. leuckarti* are scarce. Cultured populations have been studied by Ewers (1936), but to the writer's knowledge, the only quan-

titative year-round information existing on this species is in Chandler's (1940) paper. He reports *C. leuckarti* as being present in most collections, being most numerous from June to September with a maximum of 6 per liter.

When this study was begun, July 29, 1946, 24 males and 75 females per 100 liters were collected (fig. 4). The population increased rapidly after that, reaching a peak of 118 males and 250 females in early September. It is worthy of note that the peak population of *C. bicuspidatus* and *C. vernalis* far exceeded the peak population of *M. leuckarti*, which reached a peak abundance of 4 per liter. Specimens of *M. leuckarti* were last found during 1946 on November 6, when 12 females were collected. It did not appear in any of the monthly collections during the fall and winter. On May 9, 1947, one female specimen was collected, but no males were found until July 5, when 32 males and 71 females were collected. This species was collected in greatest abundance in mid-August of the second year (1947). During September and early October, the population decreased until October 14, when 39 males and 98 females were collected. Since no collections were made in November, it is not known whether or not this species was still present. On December 2, *M. leuckarti* were not found in the collections, and no more specimens of *M. leuckarti* were collected until April 24, when 6 females comprised the catch.

The temperatures at which *M. leuckarti* began to occur in the collections and the temperatures when they began to disappear from the collections were quite similar both years. *M. leuckarti* began to appear in the collections when the water reached about 8° C. It reached a peak population at about 22° C, and it began to disappear from the collections when the water temperature decreased to about 13° C.

Sex ratios. There is a paucity of information concerning the sex ratios of copepods in natural populations. Since the sexes were treated separately in this study, it is possible to see (figs. 2, 3, 4) the trends in relative abundance of males and females for the three species. The curves in figure 5 give the sex ratios of all 3 species throughout the entire study.

The ratio of females to males is high in *C. vernalis*; however, inspection of figure 5 shows that the extent to which females outnumber males is highly variable. On July 29, 1946, female *C. vernalis* were 8.6 times more numerous than males, whereas on August 12, females outnumbered males 28.8 times. This was the highest ratio between males and females. The smallest amount that females outnumbered males was 2.1 times in September, 1947. When all male and female individuals that were collected during the entire study were compared, the females on the average outnumber the males 9.5 times. Apparently the high reproductive potential of the female makes it unnecessary to have many males produced. *C. vernalis* females produce 100 to 150 eggs per clutch, and as many as 8 clutches may be produced following a single copulation. A new clutch may be produced every third day and it takes only about ten days to develop from egg to maturity (Ewers, 1936). Knowing this, it is easily understood how populations of *C. vernalis* can build up so rapidly and maintain a high population.

Females of *C. bicuspidatus* usually begin to appear in the collections about a month before the males, and the males usually disappear from the collections about a month before the females (fig. 3). On January 11 and 24 and February 11 and 26, 1947, only, females outnumbered males 13, 2, 16, and 28 times, respectively. In December, January, and February of the following year, the females outnumbered males 23, 20, and 26 times, respectively. During March, April, May, and June, when the population was apparently as well stabilized as it ever got, the females on the average outnumbered the males 3.3 times. The reproductive capacity of *C. bicuspidatus* was found to be much less than that of *C. vernalis*. *C. bicuspidatus* only produces from 50 to 80 eggs per clutch, and it requires about a month to pass from egg to maturity. These factors probably accounted for the fact that *C. bicuspidatus* never occurred in as great abundance as did *C. vernalis*.

Females do not greatly outnumber the males of *Mesocyclops leuckarti* (figs. 4, 5). When this species began to show up in the collections in the spring, the females occurred first, and in the fall, when the species began to disappear from the collections, the males disappeared first. During these times, the females outnumbered the males from 6 to 17 times. However, after males began to appear, the ratio of females to males stayed quite uniform. In collections where both males and females were found, the females outnumbered the males from 1.1 to 5.3 times with the average being 2.2 females to one male. In *M. leuckarti* the reproductive capacity of the female is comparatively low. Only about 40 eggs are produced

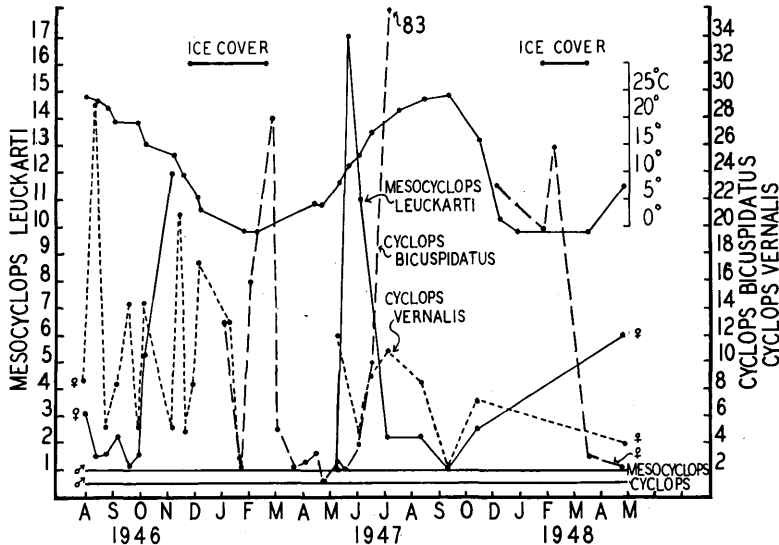


FIGURE 5. Seasonal variations in sex ratios of *Cyclops vernalis*, *Cyclops bicuspidatus* and *Mesocyclops leuckarti*. The male population was assigned a value of one and a straight line drawn to represent it. Each point on the curve indicates the number of times the females exceeded the males of the same species. Ice cover and temperature are also indicated.

TABLE 1
Monthly variations in number of copepodite and naupliar stages per 100 liters
from April, 1947, to April, 1948.

Month-Year	No. of copepod. per 100 liters	No. of naup. per 100 liters	Month-Year	No. of copepod. per 100 liters	No. of naup. per 100 liters
April, 1947	19	1039	October	136	1257
May	221	4009	December	22	83
June	950	3114	January, 1948	none	2
July	1047	3237	February	none	7
August	680	4596	March	none	74
September	217	not counted	April	16	3728

in a clutch, and it takes about 20 to 30 days for an adult to develop from an egg (Ewers, 1936). From the results of this study, *M. leuckarti* apparently requires about one male for every two females. This is a much higher percentage of males than was found to be characteristic of *C. vernalis* and *C. bicuspidatus*.
Copepodite and Nauplii. During the last year of this study, all copepodite and naupliar stages of each sample were counted and recorded (table 1). When more than one collection was taken in a month, the results were averaged. It can be seen by examination of table 1, that the greatest number of copepodite stages

were collected in July, August, and September. In mid-June, *C. bicuspidatus* adults reached their peak population, and in July *C. vernalis* adults reached their peak population. Since *C. vernalis* passes from egg to adult in about a week, it was believed that most of the copepodite stages collected in July were *C. vernalis*. The greatest number of nauplii were collected in August. Since *C. bicuspidatus*, which reached its adult peak population in mid-June, requires a month or more to pass from egg to adult, it was believed that some of the naupliar stages were *C. bicuspidatus*. The greatest percent of the nauplii, however, must have been *C. vernalis*. Since *C. vernalis* passed its peak adult population in mid-July, it is reasonable to conclude that numerous *C. vernalis* nauplii should be present in early August. Pennak (1949) noted that the peak of abundance of copepodids and adults were usually in the same month for *C. bicuspidatus* and that the nauplii abundance

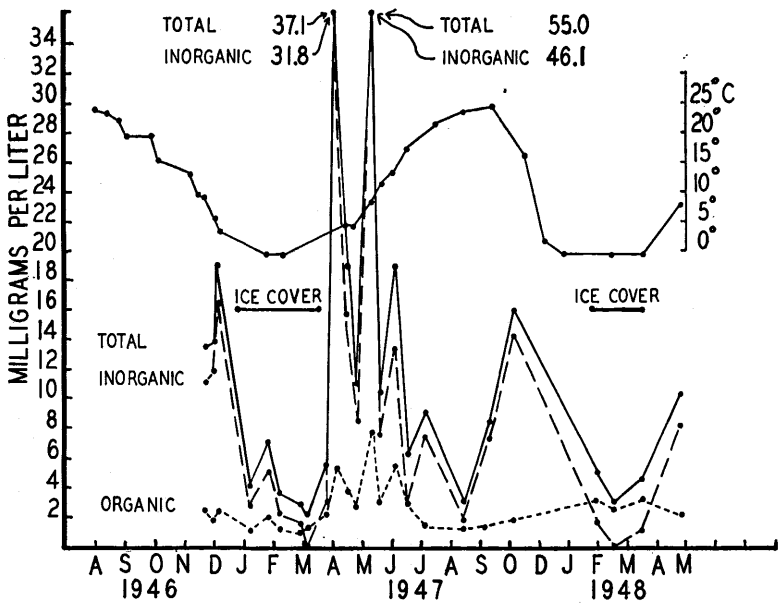


FIGURE 6. Seasonal variations in seston and temperature.

peaks preceded the adult peaks by one or two months. The writer believes this is true for *C. bicuspidatus* in western Lake Erie, but the peaks of abundance for *C. vernalis* adults and nauplii are almost simultaneous since they have such a high reproductive capacity and short life cycle.

Seston. The seasonal occurrence of plankton has been studied in many lakes, but there is very little information on seasonal variations in abundance of seston. Some investigators have estimated seston production on a single or at most a few surface samples. More extensive seston studies have been made on natural water by Birge and Juday (1934), Chandler (1942), and Pennak (1949). Birge and Juday (1934) made summer determinations on 529 Wisconsin lakes, and they found the mean organic seston to be 1.36 mg per liter. Pennak (1949) made year-round organic seston determinations on seven Colorado reservoir lakes and found the following mean annual organic to be: 1.19; 1.74; 1.78; 1.91; 2.35; 4.66; and 13.64. Chandler (1942) working year-round on western Lake Erie stated, "The organic component of this suspended matter varied from a maximum of 4 mgs. per liter in November and December, 1949, to a minimum of 0.2 mgs. per liter in January, 1940."

In this study seston samples were taken at least once each month from November, 1946, to April, 1948 (fig. 6). The writer believes that the points on the organic seston curve of figure 6 are representative of the *standing crop* (Clarke, 1946) of plankton in western Lake Erie. The total seston varied from 2.2 mg per liter on March 18, 1947, to 55.0 mg per liter on May 9, 1947. The mean annual total seston was 12.12 mg per liter. The inorganic seston varied from 0.5 mg per liter on February 16, 1948, to 46.1 mg per liter on May 9, 1951. The mean annual inorganic seston was 9.3 mg per liter, which accounts for most of the total seston. The organic seston, which is indicative of the standing crop, varied from 1.2 mg per liter on January 11, 1947, to 7.9 mg per liter on May 9, 1947. The mean annual standing crop or amount of organic seston was 2.8 mg per liter. All of the above data agree with the findings of Chandler (1942).

It has been assumed by many investigators that the plankton constitute most of the seston. This is a valid assumption excepting in instances when wind-storms resuspend bottom materials containing organic matter. If one examines figures 2, 3, 4, 5 carefully, it soon becomes evident that on April 4, when the organic matter measured 5.3 mg per liter, *Cyclops bicuspidatus* was present only in restricted numbers. From other data collected, but not treated in this paper, it is known that *C. bicuspidatus* constituted nearly all of the zooplankton population and that the phytoplankton population was very low. Apparently the increase in both organic and inorganic seston was due to wind action resuspending bottom materials. On May 9, when zooplankton and phytoplankton populations were relatively low, inorganic and organic seston were most abundant. Resuspended bottom materials accounted for high percentage of this seston (Andrews, 1948). At other times during this study, the organic seston resulted primarily from plankton.

CONCLUSIONS

The writer has reached the following conclusions: (1) that frequent representative samples must be taken the year-round, if standing crops, seasonal abundance and other population dynamics are to be ascertained; (2) that organic seston is a good index to standing crop of plankton, excepting during periods when wind has resuspended bottom materials; (3) that in western Lake Erie, *C. bicuspidatus* is a cold water monocyclic copepod while *C. vernalis* and *Mesocyclops leuckarti* are relatively warm water forms that are monocyclic or dicyclic.

SUMMARY

1. Seasonal variations in relative abundance of adult male and female *Cyclops vernalis* Fischer, *Cyclops bicuspidatus* Claus, and *Mesocyclops leuckarti* (Claus) from July 29, 1946, to April 24, 1948, are presented.

2. *Cyclops vernalis* was found to be a spring, summer and fall form, reaching maximum abundance in late June or early July when the water temperature was about 20° C. The females outnumbered the males on the average of 9.5 to one.

3. *Cyclops bicuspidatus* was found to be a winter and early spring form, reaching maximum abundance in late May or early June, when the water temperature was about 15° C. The females outnumbered the males on the average of 3.3 to one.

4. *Mesocyclops leuckarti* was found to be an early summer and fall form, reaching a maximum abundance in August or September when the water temperature was about 22° C. The females outnumbered the males on the average of 2.2 to one.

5. Seasonal variations in mean water temperatures are presented, and the durations of ice covers are indicated.

6. Seasonal variations in inorganic and organic seston are presented. Organic seston, when determinations are made monthly throughout the year, is a good index to standing plankton crop, except when bottom materials have been resuspended.

7. It is concluded that meaningful population dynamics can be ascertained only through analyzing results obtained from year-round representative samples taken at frequent intervals.

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